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Research Article

Comparing diversity of the terrestrial mammal communities inhabiting native forests and exotic plantations in southern Chile

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Abstract

The mammal community of the Coastal Range of southern Chile has been little studied even though they inhabit an environment under severe threats due to anthropic disturbance. During the spring-summer seasons of 2020–2021 and 2021–2022, we characterized the communities of wild terrestrial mammals in a native forest (NF) and an exotic plantation of *Eucalyptus* (PL) of the Coastal Range of Osorno province by phototrapping. We used 1,060 camera-trap days in the NF and 960 camera-trap days in the PL to explore the effect of habitat type on wild mammal diversity in two localities (L-1 and L-2). We quantified the species richness, abundance, community similarity and daily distribution of mammal communities. Species richness was higher in the NF (7–8 spp) than in the PL (3–4 spp). Two community similarity index (CSI) was significantly higher between native forests (CSI = 0.728 ± 0.088) than between *Eucalyptus* plantations (CSI = 0.211 ± 0.097) (95% CI). Mean abundance was also higher in the NF than in the PL (L-1: 0.011 vs. 0.004 occurrence/camera-trap day (OCT); L-2: 0.008 vs. 0.004 OCT). In L-1, the most abundant mammals in the NF were *Leopardus guigna* (45.3% of relative occurrence (RO)) and *Pudu puda* (18.9% RO), and in the PL, they were *Lycalopex culpaeus* (50% RO) and *L. guigna* (37.5% RO). In L-2, the highest abundances in the NF were for *P. puda* (34.5% RO) and *Puma concolor* (27.6% RO), while in the PL, *P. puda* was predominant (66.7% RO). In NF of both localities, 22.2% of melanic *L. guigna* individuals were observed. The highest frequency of occurrences in both locations was between 12:00 and 23:59 hours, with 60% and 76.9% of detections, respectively. The species richness found in native forest is in accordance with studies carried out in other temperate rainforests of southern Chile. In addition, native forests support a richer and more similar community of terrestrial mammals than exotic forest plantations, which indicates that native forests are the main habitat for most mammals detected and that exotic plantations function as a complementary habitat for some species.

Key words: abundance, biodiversity, camera traps, community similarity, species richness

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Introduction

Assessing mammal richness in the temperate rainforest of southern Chile (39 to 44°S) is important to increase the knowledge of the spatial use of forest habitats by the mammal fauna in this geographic area and understand the temporal dynamics of the mammal assemblages. This information is relevant for conservation purposes given that the native forest in the Coastal Range of southern Chile contains plants and animals with a high level of endemism; as a result, this area represents a biodiversity hotspot of global importance (Myers et al. 2000; Nahuelhual et al. 2007). However, despite their importance for the conservation of biodiversity, at local and global scales, these forest formations have endured a rapid rate of destruction and degradation due to anthropogenic causes (Myers et al. 2000; Echeverría et al. 2006, 2007). For example, according to Lara et al. (2012), the loss of native forest in the Los Ríos and Los Lagos regions, was a consequence of 25% of their area being replaced by grasslands and 27% by bushes. In addition, the fragmentation process of the native forest distributed in southern Chile during recent decades along with their replacement by exotic plantations for wood production is another factor of particular concern (Echeverría et al. 2006, 2007). In fact, in Osorno Province between 2006 and 2013, the area with exotic plantations increased significantly (+20.6%), a large part of this growth being at the expense of the original native forest (CONAF-UACh 2014).

The Coastal Range of the Los Ríos and Los Lagos regions in southern Chile is an area that comprises 683,694 ha (39°24'–41°45'S latitude) and harbors a typical and relatively well-preserved coastal temperate forest (Pliscoff et al. 2005). In particular, the Osorno Province, which is located in the northern part of the Los Lagos Region, approximately 42.9% of the area contains native forest (CONAF-UACh 2014), mostly distributed in the Coastal and Andes mountain ranges (Miranda et al. 2017). The Coastal Range contains a high level of endemism and a great representativeness of ancient phylogenetic lineages, and, due to these characteristics, it was declared a priority site for the conservation of biodiversity by the Ministerio del Medio Ambiente (MMA 2022) of the Chilean government. However, this geographic area is highly threatened by exotic plantations, illegal logging and forest fires.

Studies carried out on mammal diversity in the Coastal Range of southern Chile are limited since the number of monitored geographic areas has been relatively scarce, which makes it difficult to establish clear distributional patterns of species (Smith-Ramírez et al. 2019). Most studies carried out in this geographic area have focused mainly on birds, lizards and amphibians, and mammals were the least studied group of terrestrial vertebrates. Thus, increasing the knowledge about the mammal diversity of the Coastal Range of southern Chile is relevant to provide data on species richness to aid the conservation of mammal diversity in the coastal native forest. This is especially important for the species that are most susceptible to extinction in the short term and endemic to a restricted geographical area or that have reduced population sizes (Höglund 2009; Isik 2011). In this way, evaluating the diversity of wild mammals fauna in the temperate rainforest of southern Chile represents a contribution to the world efforts dedicated to nature conservation (Mittermeier et al. 2005), especially in areas with high human perturbation.

There have been a number of ecological studies on native mammals inhabiting temperate rainforests in southern Chile; however, most of them have focused on individual species (e.g., Rau and Jiménez 2002; Rodas-Trejo et al. 2010; Silva-Rodríguez et al. 2010; Sade et al. 2012; Skewes et al. 2012; Gálvez et al. 2013; Delibes-Mateos et al. 2014a). Despite this progress, the analysis of terrestrial mammal communities inhabiting temperate rainforests in southern Chile has been less addressed (Delibes-Mateos et al. 2014b; Sanino et al. 2016). These studies have been carried out in a limited number of sites of temperate rainforests, and further studies are necessary to increase the information on terrestrial mammal diversity to gather a more complete view of their habitat use. Nonetheless, these studies have reported interesting data on species richness, ranging from eight to ten species, and abundance of terrestrial mammals that inhabit some reserves (Delibes-Mateos et al. 2014b; Sanino et al. 2016).

Studies on wild mammal diversity in exotic forest plantations distributed in Chile have been less addressed. This issue is relevant given that, in Chile, large areas of native forest have been replaced with exotic forest plantations for commercial production (Miranda et al. 2017), and little is known about their effect on mammal diversity. Understanding the responses of wild mammals to exotic forest plantations is relevant to assess the effectiveness of environmental practices implemented by the forest industry, which is usually supported by the certification process (in our country, the Forest Stewardship Council (FSC) and the CERTFOR/PEFC Chile). There is increasing evidence supporting the negative effect of exotic forest plantations on mammal diversity in some South American countries (Umetsu and Pardini 2007; Pardini et al. 2009; Rodas-Trejo et al. 2010; Rosa and Vieira 2010; Grazzini el al. 2021). In fact, in *Eucalyptus* forests, an impoverished community has been observed when compared to native patches (Gheler-Costa et al. 2012). Other reports show that the number of species using forest plantations is almost half of those using native patches (Hobbs et al. 2003), with small mammals showing small richness and abundance of forest plantations in the neo-tropics (Prevedello and Vieira 2010; Martin et al. 2012; Grazzini el al. 2021). There is also evidence that species richness and abundance in exotic forest plantations are greater in areas closer to native vegetation remnants, which may be related to the positive ecotone effect (Barnett et al. 1977; Friend 1982). However, there are several studies that show that plantation forests may provide valuable habitat for species, whose use is highly dependent on the species, community and landscape structure (Brockerhoff et al. 2008). In Chile, it has been stated that a well-developed understorey in exotic forest plantations has been indicated as possibly useful as a surrogate habitat for native species, thus mitigating the negative effect of forest plantations on species richness (Simonetti et al. 2013). In Brazil, the presence of the understorey in exotic forest plantations has been identified as an important factor determining the species diversity (Stallings 1991; Rosa and Vieira 2010). Experimental data obtained in central Chile support the positive effect of well-developed undergrowth of pine plantations on the occurrence of native mammals, such as, *Leopardus guigna*, *Lycalopex culpaeus*, *Conepatus chinga*, and *Pudu puda* (Simonetti et al. 2013). Other studies carried out in southern Chile indicate that in geographical areas that contain mixed forest (exotic plantations of *Eucalyptus* and native forest), some carnivores, such as *Puma concolor* and *Pseudalopex griseus*, positively select the native forest, avoiding exotic forest

plantations as a complementary habitat (Rodas-Trejo et al. 2010). However, contradictory results were reported in pine plantations distributed in this geographical area (Zúñiga et al. 2009).

Our study aimed to characterize and compare the communities of wild terrestrial mammals inhabiting the native forest and the exotic forest plantation of two localities of the Coastal Range of the Osorno Province, southern Chile, to explore the effect that these two types of environment have on wild mammal diversity. Considering that the available evidence indicates that exotic forest plantations are less suitable for native mammal species (Umetsu and Pardini 2007; Pardini et al. 2009; Rosa and Vieira 2010; Rodas-Trejo et al. 2010; Grazzini el al. 2021), we hypothesize that exotic forest plantations of *Eucalyptus* will present a reduced richness and diversity than native forests.

Methods

Study area

We carried out the study in the Coastal Range of the Osorno Province, in two locations that contain native forest and plantations of *Eucalyptus nitens* (Fig.1). One location is located to the west of the Purranque district in a site called Los Riscos (40°53'12"S, 73°30'56"W), and the other to the west of the Río Negro district, which comprises a wide site of the native forest in the vicinity of the Huellelhue Indigenous Community (40°47'29"S, 73°33'29"W) and also an exotic plantation in the neighboring site of Putrihue (40°47'49"S, 73°28'34"W) (with about 4.4 km separating both sites). The two studied locations are in the interface between the central valley depression and the Coastal Range, which has altitudes ranging from 100 to 700 m asl.

The Los Riscos location comprises an area of 2,687 ha, 53.9% of which consists of exotic *Eucalyptus* (*E. nitens*) forest plantations. These plantations correspond to mostly mature *Eucalyptus* plantations older than 10 years (Forestal Anchile Ltda. 2021), whose harvest is carried out when they reach 16 years (Forestal Anchile Ltda. 2023). In this area, there are fragments of native forest that reach 451 ha and consist of evergreen forest and mixed forests of the roble-raulí-coihue and coihue-raulí-tepa types (Forestal Anchile Ltda 2021).

The Putrihue site covers an area of 221 ha, of which about 85% consists of exotic *Eucalyptus* plantations (*E. nitens*). The rest consists of fragments of evergreen native forest, Patagonian oak (*Nothofagus obliqua*) and mixed forest.

The climate in this region is warm, temperate and rainy with a Mediterranean influence and mean annual precipitation and temperature of 2,490 mm and 12.0 °C, respectively (Errazuriz et al. 2000). The Coastal Range of south-central Chile is characterized by an average height of 500 m asl, which gradually decreases towards the south (Ramírez and San Martín 2005; Villagrán and Hinojosa 2005). This mountain range presents a vegetational formation of temperate laurifoliar rainforest that includes the Valdivian, North Patagonian and Subantarctic types (Villagrán and Hinojosa 2005). In this forest, evergreen species predominate such as Ulmo (*Ecryphia cordifolia*), Olivillo (*Aetoxicum punctatum*), Tepa (*Laureliopsis philippiana*), Luma (*Amomyrtus* luma) and various species of Myrtaceae. The subcanopy is dominated by Patagua (*Myrceugenis ovata*), Myrtle (*Myrceugenia apiculata*) and Meli (*Myrceugenia meli*) and the

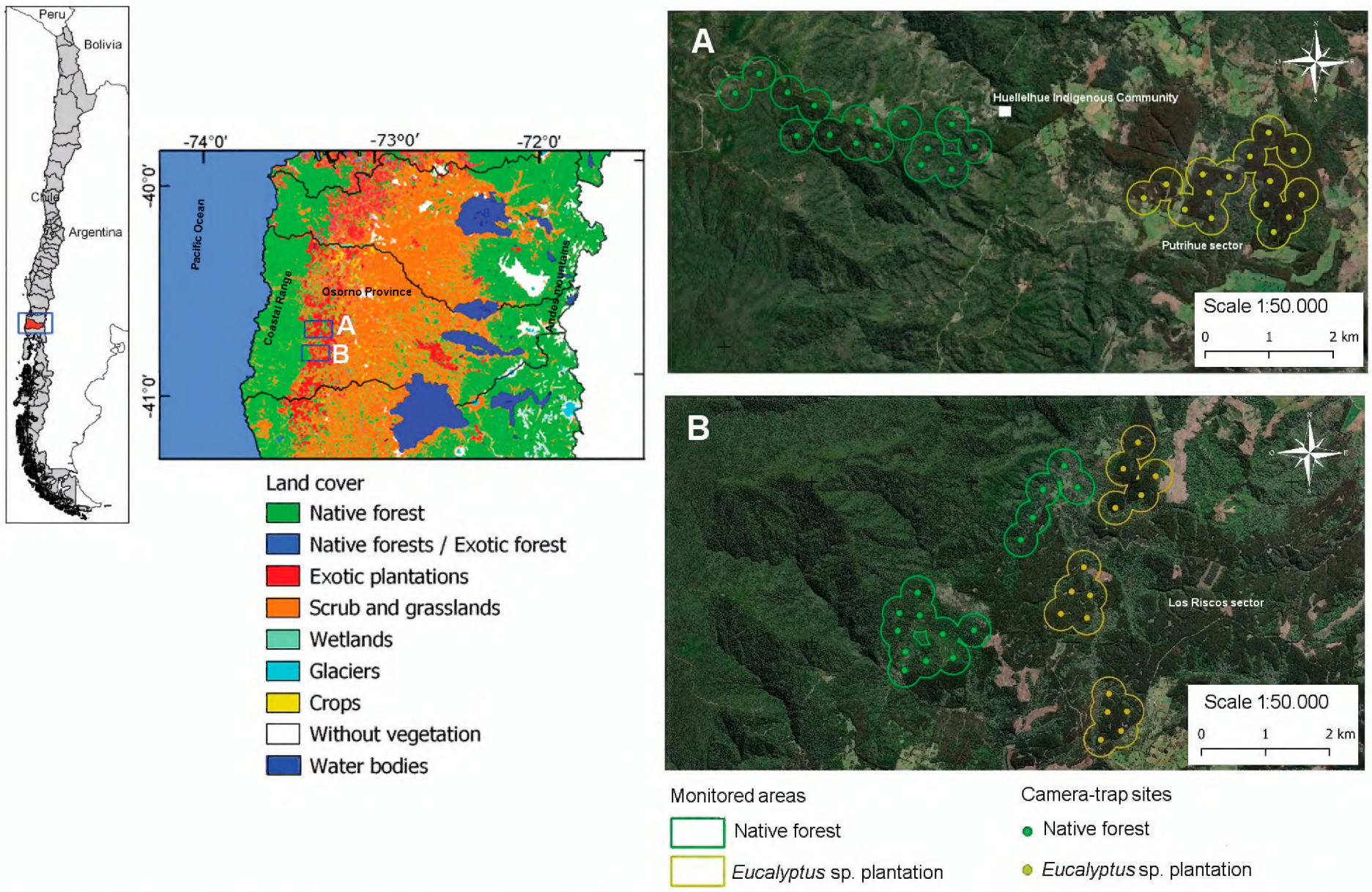

Figure 1. Map of the studied locations in the Coastal Range of Osorno Province **A** Huellelhue Indigenous Community and Putrihue sectors **B** Los Riscos sector. Monitored areas (colored lines) and camera-trap sites (color points) are indicated in each map.

understorey is usually composed of a dense layer of Quila (*Chusquea quila*) and various species of ferns (Armesto et al. 1997). This mountain range also encompasses the Valdivian Rainforest Ecoregion, which is listed among the most endangered ecoregions of the world and has a critical conservation status (Dinerstein et al. 1995; Olson and Dinerstein 1998; Miranda et al. 2017). In addition, this ecosystem is defined as a biodiversity hotspot with high conservation priority (Ormazabal 1993; Myers et al. 2000; Smith-Ramírez 2004).

Data collection

Data of terrestrial mammals were collected using camera traps, which are useful tools for identifying the presence and activity levels of mammals (Wheater et al. 2011). Between November 2020 and March 2021, we installed five camera traps in the native forest near the Huellehue Indigenous Community (NF-HC) and another five in the *Eucalyptus* plantation in the neighboring sector of Putrihue (PL-PU). (Fig. 1A). Between November 2021 and February 2022, five camera traps were installed in the native forest of the Los Riscos sector (NF-LR) and other five in the *Eucalyptus* plantation from the same area (PL-LR) (Fig. 1B). To increase the monitoring surface, we rotated the camera traps monthly between three different subareas (A, B and C) inside the native forest and the plantations, as recommended by the literature (Rovero et al. 2013). The average distance between the camera traps was 427.5 ± 92.3 m in NF-HC and 390.2 ±

59.1 m in the *Eucalyptus* plantation in the Putrihue sector. In the Los Riscos location, the distance between the camera traps reached 526.6 ±106.6 m in the native forest and 408.8 ± 68.2 m in PL-PU. This capture effort made it possible to cover a total area of 295.4 ha in NF-HC and 297.5 ha in PL-PU. The monitored area covered 303.3 ha in NF-LR and 267.5 ha in PL-LR. We calculated that each camera trap covered an area of 21 ha, assuming a home range of 6.1 km.

We used Moultrie camera traps, Model S50i (www.moultriefeeders.com), attached to the tree trunks at a height between 0.5 and 1.0 m, with the movement sensor directed towards potential areas of passage to increase the probability of photographing animals. No attractant was used because we intended to evaluate the total mammal richness and not their specific presence. The cameras were configured with a detection delay of 30 s, with low trigger sensitivity, with three triggered photos and an elapsed time interval between events of 10 s. The detection delay configuration allowed us to detect animals when they remained in range at 30 seconds between pictures. We used a low sensitivity because this configuration is recommended for short distances to avoid false triggers and when working with close-range traps in deeply wooded areas. In addition, the triggered setting allows for multiple potential image captures of the same event while reducing the chance of empty images if the subject leaves the field of view after the first shot. All camera traps were checked monthly to evaluate battery level and memory card status. In each monitored area, the camera traps were active between 27 and 55 days in NF-HC, with a sampling effort of 580 camera-trapdays, and between 27 and 34 days in PL-PU, with an effort sampling of 475 camera-trapdays. The camera traps were operating between 27 and 35 days in NF-LR and between 27 and 35 days in PL-LR, with a sampling effort of 480 camera-trap days and 485 camera-trap days, respectively. The total sum of sampling effort reached 1,060 camera-trap days in the native forest and 960 camera-trap days in the *Eucalyptus* plantation. Two or more captures of the same species by the same camera were considered independent or distinct when more than 30 min had elapsed between them (Kelly and Holub 2008; Monterroso et al. 2013). It should be noted that the monitoring of wildlife through camera traps can have biases, such as the bias of the infrared sensor in relation to body mass and not capturing species that have low population densities (Lyra-Jorge et al. 2008). However, several studies show that this monitoring method is effective in adequately characterizing biodiversity, including the fauna that inhabits neo-tropical environments (Srbek-Araujo and Chiarello 2005; Tobler et al. 2008; Munari et al. 2011). The data obtained included the sector, number of the camera traps and captures of the occurrence with the date, time of activation and species recorded. For all the analyses, we considered each activation event as a positive occurrence when the photographic record showed the presence of mammals, whether small-, medium- or large-sized, regardless of the number of positive images obtained. To carry out this task, only good images, i.e., those that showed sharpness and clarity, were used to increase animal identification.

Data processing

Species abundance was calculated as the number of individuals representing the species in the locality (i.e., absolute frequency) and as the proportion of the species recorded in the locality calculated by dividing the number of individuals

of the species by the total number of occurrences recorded in the locality (i.e., relative frequency). The proportion of individuals recorded in camera trap of each species was also calculated by dividing the total number of occurrences of the species with the total number of camera traps days achieved during the monitoring period in each location. We calculated the proportion of captures of *L. guigna* with normal and melanic fur to evaluate whether melanism influences the habitat use of this cat.

Species richness was assessed using the concept of the effective number of species or true diversity (TD) (Jost 2006). Thus, two species richness measures were calculated: TD of order q = 0, which counts species equally without regard to their relative abundances and TD of order q = 1, which counts individuals equally and thus weighs species in proportion to their abundances. The TD of order q = 1 was estimated for each forest type using maximum likelihood estimators (MLEs) under a homogeneous model (Chao and Lee 1992), through the Species Richness Estimation tool available in the online software SpadeR (Chao et al. 2015). In addition, the effect of habitat type on mammal community composition was evaluated by two community similarity measures that quantify species compositional resemblance between two communities. The similarity measure was performed with the Two-Community Similarity Measures tool available in the online software SpadeR (Chao et al. 2015) by comparing species relative abundances based on q = 1 (Horn 1966). The community similarity index ranges between 0 and 1, where 0 indicates a complete differentiation and 1 indicates full similarity. TD of order q = 1 and similarity were estimated using 1000 bootstrap replications.

To determine the variation in the daily occurrence of each species, we analyzed the number of occurrences within four hourly intervals. These intervals were defined as follows: I) 0:00 to 05:59, II) 06:00 to 11:59, III) 12:00 to 17:59 and IV) 18:00 to 23:59 hours.

Statistical analysis

The estimation of TD of order q = 1 and similarity measures were compared between habitats, whose significance were determined by overlapping of 95% confidence intervals. We used the chi-square test with Yates´ correction (χ^2_{Yates}) (Heumann et al. 2016) to verify whether the frequency of melanic individuals of *L. guigna* found in our study was consistent with the pattern of this phenotype reported in other studies carried out in other geographical areas. For this purpose, we compare our frequency of *L. guigna* melanism with the frequency of melanism reported for this felid in other native forest sites of southern Chile, such as those reported for the Senda Darwin Biological Station (Sanderson et al. (2002), Isla Grande de Chiloé (Napolitano 2011), Huinay Reserve (Delibes-Mateos et al. 2014b) and Añihue Reserve (Sanino et al. 2016).

Results

Species richness and community composition

In NF-HC and NF-LR, the detected mammals belong to seven and six families, respectively. Species richness with TD (q = 0) was higher in NF-HC (eight species)

Table 1. Species richness and abundance of terrestrial mammals.NF-HC= Native forest of Huellelhue Indigenous Community, PL-PU=*Eucalyptus* plantation of Putrihue, NF-LR=Native forest of Los Riscos, PL-LR=*Eucalyptus* plantation of Los Riscos. [#]Absolute occurrences are indicated in parenthesis, [&]CC = Conservation category according to Ministerio del Medio Ambiente of the Chilean government (2022).

Family/Species	CC[&]	Abundance (%)[#]			
		NF-HC	PL-PU	NF-LR	PL-LR
Orden Artiodactyla					
Cervidae					
Pudu deer (*Pudu puda*)	VU	18.9 (10)	0.0 (0)	34.5 (10)	66.7 (10)
Orden Carnivora					
Canidae					
Culpeo fox (*Lycalopex culpaeus*)	VU	11.3 (6)	50.0 (8)	3.4 (1)	0.0 (0)
Felidae					
Guigna (*Leopardus guigna*)	NT	45.3 (24)	37.5 (6)	10.3 (3)	13.3 (2)
Puma (*Puma concolor*)	NT	5.7 (3)	0.0 (0)	27.6 (8)	0.0 (0)
Mustelidae					
Lesser grison (*Galictis cuja*)	LC	–	–	3.4 (1)	0.0 (0)
American mink (*Neogale vison*)	–	1.9 (1)	0.0 (0)	–	–
Mephitidae					
Hog-nosed skunk (*Conepatus chinga*)	LC	0.0 (0)	6.3 (1)	6.9 (2)	0.0 (0)
Orden Lagomorpha					
Leporidae					
European hare (*Lepus europaeus*)	–	1.9 (1)	6.3 (1)	–	–
Orden Microbiotheria					
Microbiotheriidae					
Monito de monte (*Dromiciops gliroides*)	NT	15.1 (8)	0.0 (0)	6.9 (2)	0.0 (0)
Undetermined rodents		–	–	6.9 (2)	20.0 (3)
Total		100 (53)	100 (16)	100 (29)	100 (15)
True diversity (q=0)		7	4	8	3
True diversity (q=1) ± SE		7.00 ± 0.06	4.08 ± 0.29	8.25 ± 0.53	3.02 ± 0.14

and NF-LR (seven species) than in PL-PU (four species) and PL-LR (three species) (Table 1). Photographs of mammal species detected in NF-HC and NF-LR are presented in Fig. 2A–E and Fig. 2F–K, respectively, and those observed in PL-PU and PL-LR are presented in Fig. 3A, B and Fig. 3C, D, respectively. Species richness based on TD (q = 1) indicated significantly lower values (95% CI) in PL-PU than in NF-HC (4.08 vs. 7.00) and in PL-LR than in NF-LR (3.02 vs. 8.25) (Fig. 4). The two-community similarity measures revealed that species composition was more similar between the native forests (NF-HC vs. NF-LR = 0.728 ± 0.088) than between native forest and *Eucalyptus* plantations (NF-HC vs. PL-PU = 0.675 ± 0.082, NF-LR vs. PL-LR = 0.696 ± 0.086) or between *Eucalyptus* plantations (PL-PU vs. PL-LR = 0.211 ± 0.097) (Table 2). In fact, five species were shared between native forests, but only one species was shared between *Eucalyptus* plantations. In addition, the similarity measure was significantly lower in *Eucalyptus* plantations than in native forest (95% CI) (Table 2).

A
14°C 28.72inHg #MOULTRIECAM 01 DEC 2020 05:21 pm
B
17°C 28.71inHg #MOULTRIECAM 28 DEC 2020 12:28 pm
C
16°C 28.19inHg #MOULTRIECAM 16 JAN 2021 02:34 pm
D
15°C 29.43inHg #MOULTRIECAM 02 NOV 2020 03:42 pm
E
17°C 27.36inHg #MOULTRIECAM 25 FEB 2021 10:07 pm
F
20°C 29.41inHg #MOULTRIECAM 14 FEB 2022 01:40 pm
G
17°C 29.47inHg #MOULTRIECAM 26 JAN 2022 12:24 pm
H
12°C 29.10inHg #MOULTRIECAM 08 NOV 2020 01:05 am
I
19°C 29.44inHg #MOULTRIECAM 18 FEB 2021 07:36 pm
J
7°C 29.13inHg #MOULTRIECAM 14 DEC 2020 03:41 am
K
14°C 29.57inHg #MOULTRIECAM 17 FEB 2021 10:00 pm

Figure 2. Species of terrestrial mammals detected by camera-trapping in native forest **A–E** Huellelhue Indigenous Community sector **A** Pudu deer (*Pudu puda*) **B** Culpeo fox (*Lycalopex culpaeus*) **C** Guigna (*Leopardus guigna*) **D** Puma (*Puma concolor*) and **E** Monito de monte (*Dromiciops gliroides*) **F–K** Los Riscos sector **F** Pudu deer (*Pudu puda*) **G** Culpeo fox (*Lycalopex culpaeus*) **H** Guigna (*Leopardus guigna*) **I** Puma (*Puma concolor*) **J** Hog-nosed skunk (*Conepatus chinga*) and **K** Monito de monte (*Dromiciops gliroides*).

Table 2. Two community similarity index of terrestrial mammals from the Coastal Range of Osorno Province. NF-HC = Native forest of Huellelhue Indigenous Community, PL-PU = *Eucalyptus* plantation of Putrihue, NF-LR = Native forest of Los Riscos, PL-LR = *Eucalyptus* plantation of Los Riscos. Equal letters indicate overlap of the 95% confidence intervals.

Comparison	Two community similarity index (± SE)	95% CI	No. of species in community 1	No. of species in community 2	No. of shared species
NF-HC vs NF-LR	0.728 ± 0.088	0.555–0.900[a]	7	8	5
NF-HC vs PL-PU	0.675 ± 0.082	0.515–0.835[a]	7	4	3
NF-LR vs PL-LR	0.696 ± 0.086	0.527–0.864[a]	8	3	3
PL-PU vs PL-LR	0.211 ± 0.097	0.021–0.401[b]	4	3	1

Abundance

In NF-HC, 53 individuals were detected considering all recorded mammal species, while in NF-LR this value reached 29 animals (Table 1). In contrast, the *Eucalyptus* plantations showed a small number of mammal individuals, with 16

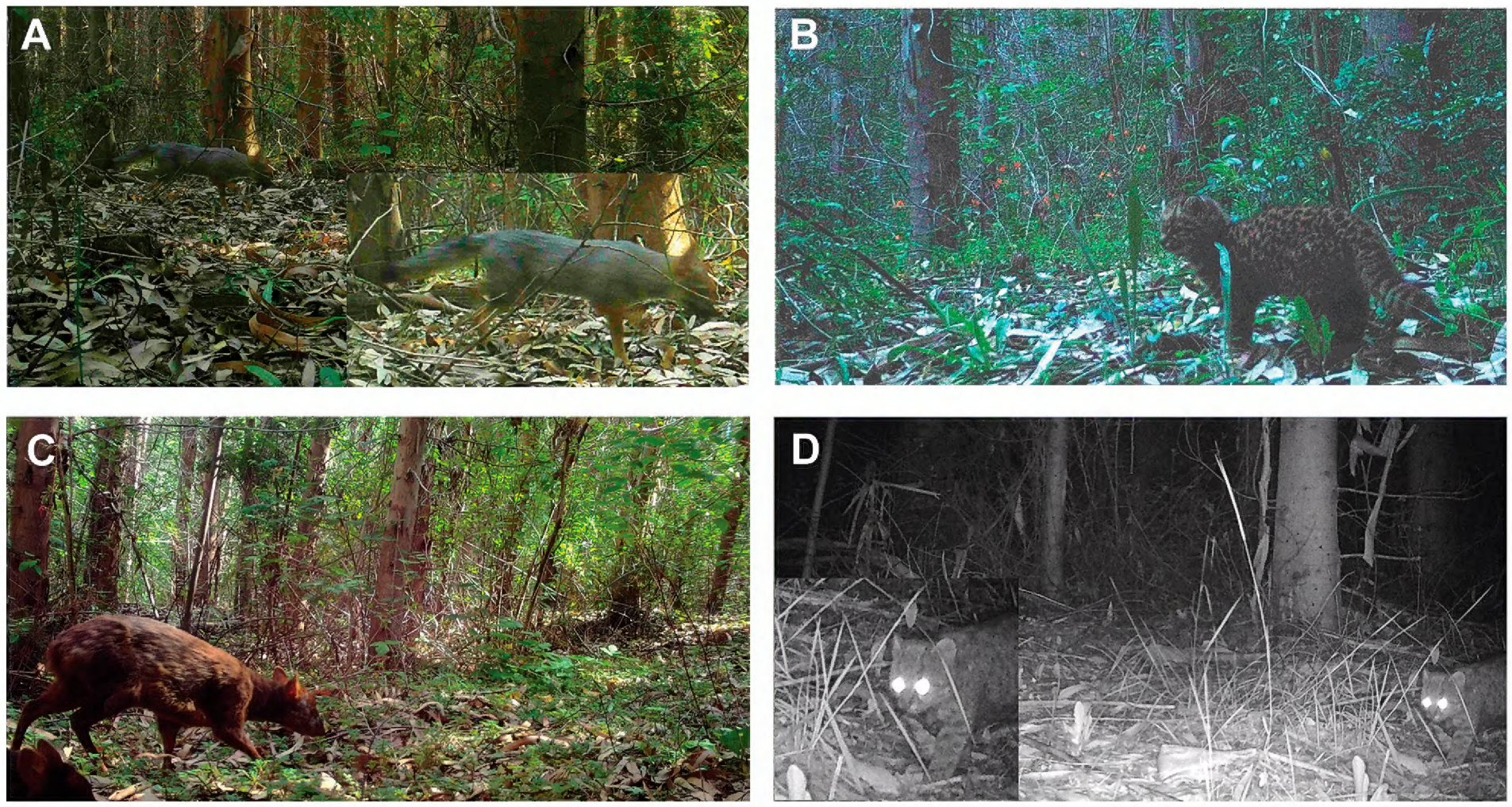

Figure 3. Species of terrestrial mammals detected by camera-trapping in *Eucalyptus* plantation **A, B** Putrihue sector **A** Culpeo fox (*Lycalopex culpaeus*) and **B** Guigna (*Leopardus guigna*) **C, D** Los Riscos sector **C** Pudu deer (*Pudu puda*) and **D** Guigna (*Leopardus guigna*).

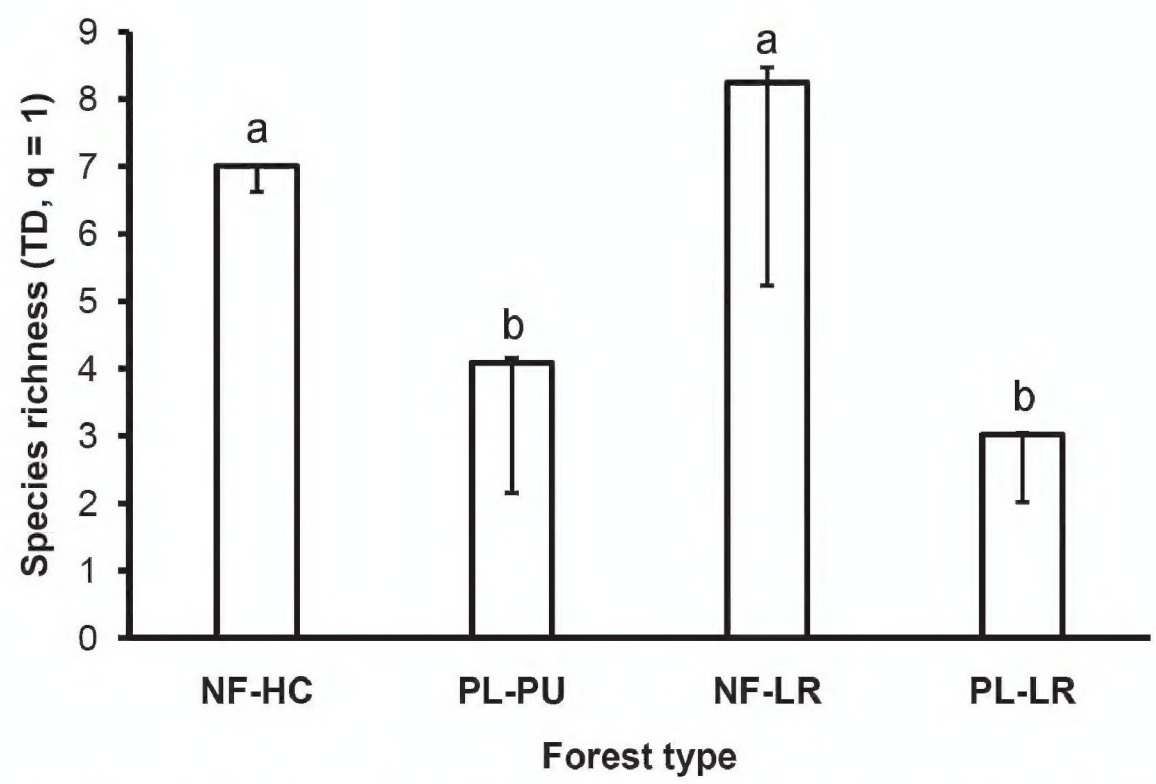

Figure 4. Bar chart representing the species richness based on TD (q = 1) of terrestrial mammal communities inhabiting four localities in the Coastal Range of Osorno Province, southern Chile. Equal letters indicate overlap of the 95% confidence intervals. NF-HC= Native forest of Huellelhue Indigenous Community, PL-PU = *Eucalyptus* plantation of Putrihue, NF-LR = Native forest of Los Riscos, PL-LR = *Eucalyptus* plantation of Los Riscos.

in PL-PU and 15 in PL-LR (Table 1). By species and forest type, *L. guigna* and *P. puda* were the most abundant in NF-HC (Fig. 2A, C), with 24 and 10 animals, respectively, and with a relative frequency of 45.3% and 18.9%, respectively. In NF-LR, *P. puda* and *P. concolor* (Fig. 2F, I) were the most frequent with 10 and 8 individuals, and with a relative frequency of 34.5% and 27.6%, respectively.

Table 3. Abundance of terrestrial mammals determined as occurrences per camera-trap day.NF-HC = Native forest of Huellelhue Indigenous Community, PL-PU = *Eucalyptus* plantation of Putrihue, NF-LR = Native forest of Los Riscos, PL-LR = *Eucalyptus* plantation of Los Riscos. #CC = Conservation category according to Ministerio del Medio Ambiente of the Chilean government (2022).

Family/Species	CC#	Abundance (occurrences/camera-trap day)			
		NF-HC	PL-PU	NF-LR	PL-LR
Orden Artiodactyla					
Cervidae					
Pudu deer (*Pudu puda*)	VU	0.017	0.000	0.021	0.021
Orden Carnivora					
Canidae					
Culpeo fox (*Lycalopex culpaeus*)	VU	0.010	0.017	0.002	0.000
Felidae					
Guigna (*Leopardus guigna*)	NT	0.041	0.013	0.006	0.004
Puma (*Puma concolor*)	NT	0.005	0.000	0.017	0.000
Mustelidae					
Lesser grison (*Galictis cuja*)	LC	–	–	0.002	0.000
American mink (*Neogale vison*)	–	0.002	0.000	–	–
Mephitidae					
Hog-nosed skunk (*Conepatus chinga*)	LC	0.000	0.002	0.004	0.000
Orden Lagomorpha					
Leporidae					
European hare (*Lepus europaeus*)	–	0.002	0.002	–	–
Orden Microbiotheria					
Microbiotheriidae					
Monito de monte (*Dromiciops gliroides*)	NT	0.014	0.000	0.004	0.000
Undetermined rodents		–	–	0.004	0.006
Mean		0.011	0.004	0.008	0.004

In PL-HC, the most abundant mammals were *L. culpaeus* (8 individuals, 50% of relative frequency) and *L. guigna* (6 individuals, 37.5% of relative frequency) (Fig. 3A, B), while in PL-LR *P. puda* was predominant (10 individuals, 66.7% of relative frequency) (Fig. 3C). *L. culpaeus* and *Conepatus chinga* were recorded in NF-HC and PL-PU, with similar frequencies in both habitats (Table 1). *P. puda* in NF-LR and PL-LR presented an equal frequency in both habitats, with 10 individuals in each case. *L. guigna* was also frequent in native forest as well as in the exotic plantations in both localities (Table 1).

The mammal abundance based on the occurrences per camera-trap day showed a mean value of 0.011 occurrence/camera-trap day in NF-HC and of 0.004 occurrences/camera-trap day in PL-PU (Table 3). In the native forest, the most abundant mammal species were *L. guigna* and *P. puda*, with 0.041 and 0.017 occurrences/camera-trap day, respectively, while in the *Eucalyptus* plantation the most abundant were *L. culpaeus* and *L. guigna*, with 0.017 and 0.013 occurrences/camera-trap day, respectively. The mammal abundance was also higher in NF-LR than in PL-LR, with mean values of 0.008 and 0.004

Table 4. Occurrences of guigna (*Leopardus guigna*) individuals with different color phenotypes in the Coastal Range of Osorno Province. #Number of occurrences are indicated in parenthesis.HC-PU = Huellelhue Indigenous Community and Putrihue sector, LR = Los Riscos sector.

Sector	Native forest			*Eucalyptus* plantation		
	Total	Non-melanic guigna (%)	Melanic guigna (%)	Total	Non-melanic guigna (%)	Melanic guigna (%)
HC-PU	24	75.0 (18)#	25.0 (6)	6	100.0 (6)	0.0 (0)
LR	3	100.0 (3)	0.0 (0)	2	100.0 (2)	0.0 (0)
Total	27	77.7 (21)	22.2 (6)	8	100.0 (8)	0.0 (0)

Figure 5. Individuals of guigna (*Leopardus guigna*) with different color phenotypes detected by camera-trapping in the native forests of the Huellelhue Indigenous Community sector **A** non-melanic guigna and **B** melanic guigna.

occurrences/camera-trap day, respectively (Table 3). In Los Riscos, *P. puda* presented the highest abundance in both habitats, with 0.021 occurrences/camera-trap day.

Melanic *L. guigna* individuals were only observed in NF-HC and NF-LR, representing 22.2% of the total occurrences (Table 4 and Fig. 5). When comparing this frequency of melanism with previous data obtained in other sites in southern Chile with a similar latitude, this value of melanism was not significantly different (Senda Darwin Biological Station=28.6%, 42°S, chi-square test: χ^2_{Yates} = 0.40, df = 1, P > 0.05; Isla Grande de Chiloé=15.8%, 42°S, chi-square test: χ^2_{Yates} = 0.66, df = 1, P > 0.05). However, when making this comparison with populations distributed further south in the country, we observed a significant difference in the frequency of melanism (Huinay Reserve=50%, 42.8°S, chi-square test: χ^2_{Yates} = 7.04, df = 1, P < 0.05; Añihue Reserve=48.1%, 43.8°S, chi-square test: χ^2_{Yates} = 6.27, df = 1, P < 0.05).

Temporal distribution

Daily activity patterns in the study area varied among species (Fig. 6). In fact, in NF-HC, *L. guigna* presented a higher absolute frequency in the first and third hourly intervals compared to the second and fourth intervals, and *P. puda* presented a high absolute frequency only in the fourth interval (Fig. 6A). Likewise, *P. concolor* presented a higher absolute frequency in the third- and fourth-hour intervals in NF-LR (Fig. 6C). In general, the detection of mammals in NF-HC was concentrated from 0:00 to 05:59 h (30%; n=12) and from 12:00 to 23:59 h (60%;

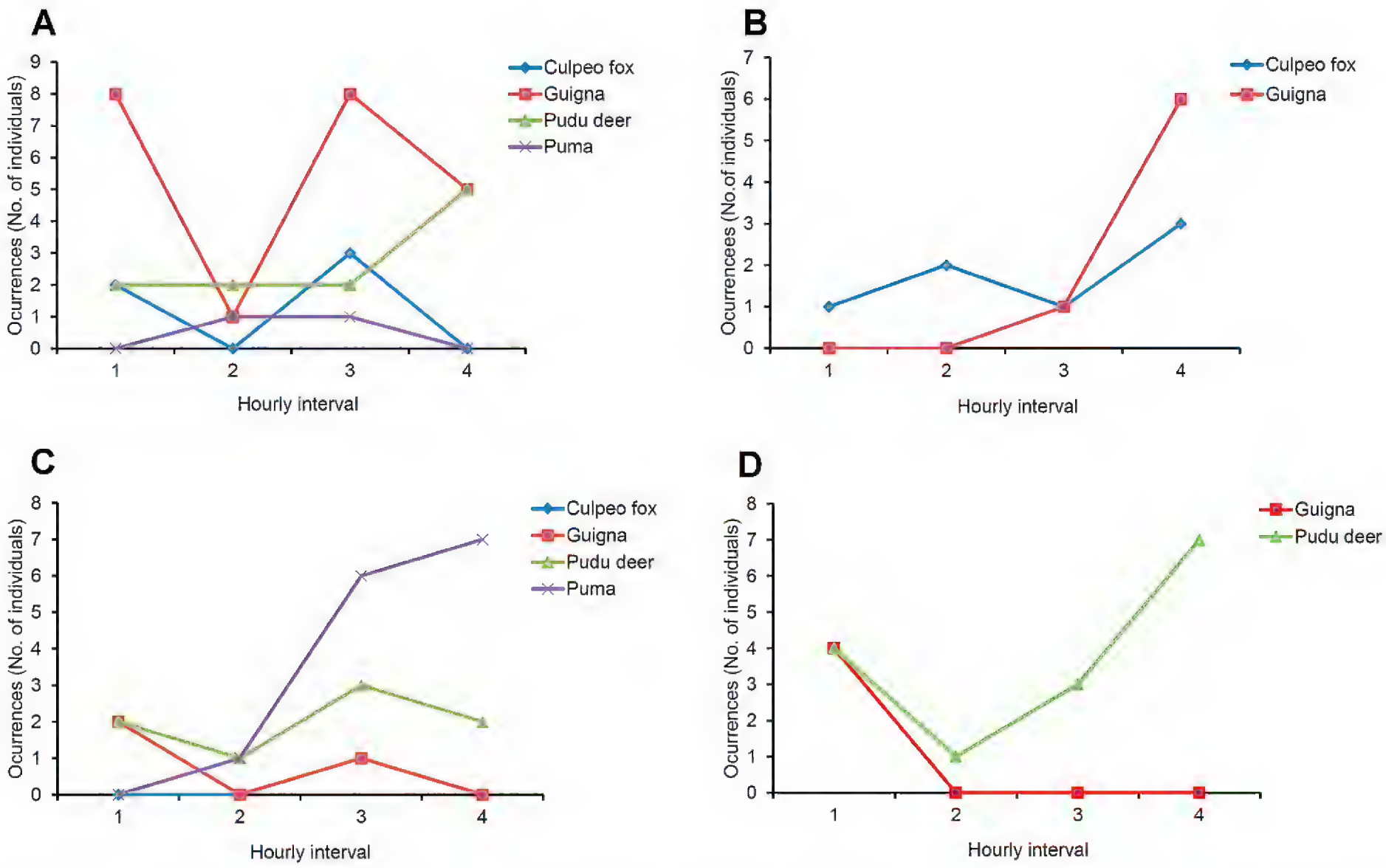

Figure 6. Variation in the daily occurrence for different species of terrestrial mammals within four hourly intervals **A** Native forest of Huellelhue Indigenous Community sector **B** *Eucalyptus* plantation of Putrihue sector **C** Native forest of Los Riscos sector and **D** *Eucalyptus* plantation of Los Riscos sector. Hourly Intervals were defined as follows: 1) 0:00 to 05:59, 2) 06:00 to 11:59, 3) 12:00 to 17:59 and 4) 18:00 to 23:59 hours.

n = 24), and the greatest diversity of occurrences in this area occurred between 12:00 and 17:59 with four species. In NF-LR, the detection of mammals was also high between 12:00 and 23:59 h (76.9%, n=20), with the greatest diversity of occurrences between 12:00 and 17:59 h with four species. Regarding the temporal distribution of mammals within the plantations, we observed that in PL-PU the detection of mammals was concentrated from 18:00 to 23:59 h (63.3%, n = 9) (Fig. 6B) and in PL-LR from 0:00 to 05:59 h and from 18:00 to 23:59 h (78.9%, n=15) (Fig. 6D).

Discussion

The result of species richness recorded in this study for the terrestrial mammal communities found in the native forest of the Coastal Range of Osorno Province, is similar to that reported in studies conducted in other geographical areas of southern Chile. In fact, the species richness found in Huellelhue Community and Los Riscos, which varied from seven to eight species, it is within the range reported in other temperate rainforests of southern Chile. For example, Sanino et al. (2016), using camera-traps, also reported eight species belonging to the orders Carnivora, Artiodactyla and Rodentia in the Añihué Reserve in the northern part of the Aysén Region (43°48'S, 72°58'W). In addition, Delibes-Mateos et al. (2014b) reported 10 terrestrial mammals in temperate rainforests of southern Chile located in the Huinay reserve of the Los Lagos Region (42°22'S,

72°24'W) using three detection methodologies (questionnaires to residents and visitors, transects of mammal presence and camera-trapping). We recorded the presence of three species of carnivores in the native forest of the studied area, namely *P. concolor*, *L. culpaeus* and *L. guigna*. The abundance of these species was relatively high in the studied area, varying between 0.002 and 0.041 occurrences/camera-trap days, with *L. guigna* being the most abundant species among all the carnivores identified with 0.041 occurrences/camera-trap days. The abundance of *L. guigna* is similar to values reported for this parameter in studies carried out in areas further south of our study sites. For example, in the Añihue Reserve this feline presented a value of 0.034 occurrence/camera-trap days (Sanino et al. 2016), and in Huinay Reserve, this species showed a value of 0.035 occurrence/camera-trap days (Delibes-Mateos et al. 2014b). However, our result of abundance is higher than that reported by Gálvez et al. (2013), who reported only 0.001 occurrences/camera-trap day for *L. guigna* distributed in fragmented native forest located to the north of our study area during spring-summer of 2008–2009 (Pucón district, La Araucanía Region). Therefore, the high abundances of *L. guigna* observed in the study areas may be related to their relatively good conservation, which emphasizes the importance of maintaining a large surface area of undisturbed native forest to better conserve this emblematic and near-threatened (MMA 2022) carnivorous species. In addition, it is likely that the diminished presence of a dense understorey in exotic *Eucalyptus* plantations is a factor that limits the presence of melanic *L. guigna* in exotic forest plantations. This is a possible explanation given that *L. guigna* is a species with a wide home range, of approximately 261 ha (Dunstone et al. 2002), a characteristic that would potentially allow them to colonize exotic forest plantations close to native forests. In addition, from the conservation point of view, *Eucalyptus* plantations would be an unsuitable habitat for the long-term conservation of the different fur color phenotypes of *L. guigna*.

Our results show that the abundance of terrestrial mammals in the native forest was higher than in the exotic plantations. In fact, in the Huellelhue Community sector, the mean abundance in the native forest was 0.011 occurrences/ camera-trap days, while in the *Eucalyptus* plantation of Putrihue this parameter reached a value of 0.004 occurrence/ camera-trap days. This result is consistent with previous studies of the abundance of carnivores, for example, *P. concolor* and *P. griseus*, among mature and recent plantings of *Eucalyptus* versus existing native forest in the Purranque district, a study that showed a positive and significant selection for the native forest habitat and a negative selection for the recent plantations of *Eucalyptus* (Rodas-Trejo et al. 2010). However, our results differ from those published by Zúñiga et al. (2009), who found that puma and chilla fox in the Araucanía Region (Rucamanque site) preferentially select pine plantations over the native forest. Therefore, it appears that the non-use of exotic forest plantations by pumas and foxes depends on their vegetation structure. Several factors may determine the use of pine plantations by native mammals. For example, there is evidence that a well-developed understorey in pine plantations is an important attribute that favors the presence of foxes and other mammals in Central Chile (Simonetti et al. 2013). This is also consistent with the results of Rosa and Vieira (2010), who reported that the understorey positively influenced the presence of small mammals in pine plantations of Rio Grande do Sul, Brazil.

We expected exotic plantations to present lower species richness as reported in previous studies (Umetsu and Pardini 2007; Pardini et al. 2009; Rodas-Trejo et al. 2010; Rosa and Vieira 2010; Grazzini et al. 2021). Our results support this hypothesis given that species richness was significantly lower in the exotic plantations than in native forest in the two analyzed localities. In addition, community similarity measures revealed that, between the *Eucalyptus* plantations, the species composition was more dissimilar than between the native forests, indicating that mammal communities of native forests have a higher composition resemblance than that of exotic plantations. This result is consistent with the available evidence since in exotic plantations and reforested forest areas assemblages are usually distinct (Umetsu and Pardini 2007; Pardini et al. 2009; Rosa and Vieira 2010; Grazzini et al. 2021). Therefore, these results support that exotic plantations of *Eucalyptus* negatively affect the local diversity of the terrestrial mammal in the Coastal Range from southern Chile.

In addition, we observed species with some preference for *Eucalyptus* plantations over native forests, in particular, *L. culpaeus* and *C. chinga*. *P. puda* followed a similar pattern, given that their abundance was quite similar between both habitats in Los Riscos. These results reveal that these species expressed high plasticity in their habitat use, allowing the use of native forest and *Eucalyptus* plantations. Although further monitoring efforts with camera traps will be required to better support this pattern, it is likely that exotic forest plantations could have compositional characteristics that favor the presence of these species. Some studies have indicated that the presence of an understorey could be a relevant factor that influences diversity of mammal species in both *Eucalyptus* plantations (Stallings 1991) and pine plantations (Rosa and Vieira 2010; Simonetti et al. 2013). In fact, experimental data obtained in central Chile support the positive effect of a well-developed undergrowth of pine plantations on the occurrence of different native mammals, including *P. puda* (Simonetti et al. 2013). Thus, in the analyzed localities, the *Eucalyptus* plantations may function as a surrogate habitat for some mammal species, mitigating to some extent the negative effect of plantations on species richness. In addition, the process of surrogation of the *Eucalyptus* plantation may also be associated with the generalist feeding of these species, which may determine their tendency to occupy disturbed environments. This explanation is plausible given that available data indicate that *L. culpaeus* and *C. chinga* are generalist species (Donadio et al. 2004; Medina et al. 2009; Lobos et al. 2020). In Brazil, the positive effect of *Eucalyptus* plantations on the abundance of small mammals, especially the more generalist species, has also been observed (Rosalino et al. 2014).

The detection of the species in native forest of the Huellelhue Community was concentrated mainly between 12:00 and 23:59 h, while the greatest diversity of occurrences in this same area occurred between 12:00 and 17:59 h, with at least four species. The same pattern of sightings and diversity of occurrences was observed in the Los Riscos sector. These results are consistent with the nocturnal behavior of Chilean mammals (e.g., Jaksic and Simonetti 1987; Iriarte 2010; Delibes-Mateos et al. 2014a). In particular, *P. puda* showed an increase in activity during twilight, which could be part of an evasion strategy against diurnal predators. *L. guigna* also showed greater crepuscular activity both in the native forest and in *Eucalyptus* plantation. Although additional studies are required to confirm the existence of this pattern, studies in other areas

of native forest in southern Chile, such as that carried out in the Huinay Biological Reserve (Hernández 2010, Delibes-Mateos et al. 2014b), indicate that its occurrence could be related to a greater availability of small mammal prey during twilight.

Finally, the existence of melanism in *L. guigna* is a phenomenon of common occurrence in Chile, whose incidence in different populations distributed in the national territory varies from 0% to 90.9% (Sanino et al. 2016). Some authors have related the level of incidence of melanism with the increase in the geographical latitude of the populations (Miller et al. 2015), which seems to be related to the decrease in environmental temperature in sites located at higher latitudes (Sanino et al. 2016). Our data showed a 22.2% melanic individual incidence that agrees with values of melanism incidence observed in populations distributed in similar latitudes, such as those inhabiting the Senda Darwin Biological Station (28.6%, Sanderson et al. 2002) and the Isla Grande de Chiloé (15,8%, Napolitano 2011). However, this level of *L. guigna* melanism was discordant with respect to those found in populations distributed further south of the country, such as those of Huinay Reserve (50%, Delibes-Mateos et al. 2014b) and the Añihue Reserve (48,1%, Sanino et al. 2016). Thus, our results add support to the belief that the frequency of melanism in *L. guigna* vary as a function of the latitudinal location of the populations. Likewise, a higher frequency of melanic *L. guigna* in colder areas of southern Chile is probably related to an adaptive advantage provided by this phenotype in densely forested environments. Melanic fur can provide greater camouflage capacity, rendering them less visible to prey and favoring their hunting process. In fact, in South American felids the presence of specimens with melanic fur has been related to a greater adaptive advantage in certain environments compared to typical fur (Schneider et al. 2012). In our study area, the native temperate forest has an understorey composed mainly of a dense layer of quila (*Chusquea quila*) and various species of ferns (e.g., *Lophosoria quadripinnata* and *Blechnum chilense*) (Luebert y Pliscoff 2006), with a low incidence of light at ground level, favoring the melanic phenotype of *L. guigna*. This could also explain the reduced detection rates of melanic *L. guigna* in the *Eucalyptus* plantations, probably because this habitat lacks a dense understorey, increasing the light intensity at ground level and, thus, the visibility of melanic individuals. Therefore, it is likely that the diminished presence of a dense understorey in exotic plantations of *Eucalyptus* deters the presence of melanic *L. guigna*, a finding that is more striking when we consider that individuals of different fur color phenotypes could migrate to this habitat, as this species has a wide home range (approx. 261 ha, Dunstone et al. 2002). However, from the conservation point of view, exotic plantations of *Eucalyptus* would be an exotic habitat that is not very favorable for long-term conservation of the different fur color phenotypes of *L. guigna*.

Conclusion

Our results support that exotic plantations of *Eucalyptus* reduce the local diversity of the terrestrial mammal of the Coastal Range from southern Chile. This result highlights the importance of increasing the efforts aimed at the conservation of native forests and strengthening reforestation policies as a strategy to reduce the effect of exotic forest plantations on native mammal

diversity. This issue is not trivial, given that native forest in southern Chile has experienced an important reduction during recent decades (approximately -25%, Lara et al. 2012), a process that is likely to continue due to different factors, such as illegal logging and forest fires. However, it appears that exotic plantations of *Eucalyptus* have compositional characteristics that favor the presence of some native species in this habitat (e.g., *L. culpaeus* and *P. puda*), a pattern that has been observed in other localities of Chile and in mammalian communities inhabiting other countries of South America. However, *Eucalyptus* plantations appear to affect the presence of melanic *L. guigna*, which reveals that this habitat is unsuitable for the long-term conservation of the different fur color phenotypes of this species. Considering that *Eucalyptus* plantations will continue to exist given their economic importance in the national forest industry, forestry companies should implement specific management practices to protect the native mammal fauna that inhabits these areas as a surrogate habitat.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Nelson Colihueque conceived the manuscript, and performed literature revision and manuscript preparation. Víctor Vidal performed field work and selected camera trap sites based on geographical information system (GIS). Contanza Vásquez performed field work and reviewing of the manuscript. Alberto Gantz reviewing and editing of the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text.

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